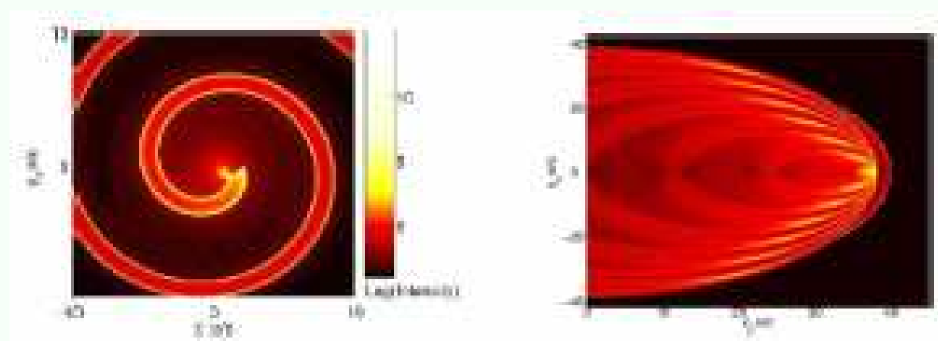
Construction and use of superluminal emission technology demonstrators with applications in radar, astrophysics and secure communications

- Superluminal = faster than light *in vacuo*.
- Does not break laws of physics $\Rightarrow$ electromagnetic equivalent of "sonic boom".
- *New type of solid-state light source*.
- Source travels faster than its wave-speed $\Rightarrow$ signal arriving at observer can contain contributions from multiple retarded times.
- DR builds on ER combining practical demonstration of concept with numerical simulations (right) relevant to radar (patent), communications and astrophysics [pulsars] (papers).
- Time is ripe to build on this work for programmatic (Grand Challenges B, D, and G), commercial and fundamental science applications.
- We must maintain our current lead in this emergent field (competitors in Russia).

Demonstration (above) and simulation (below).

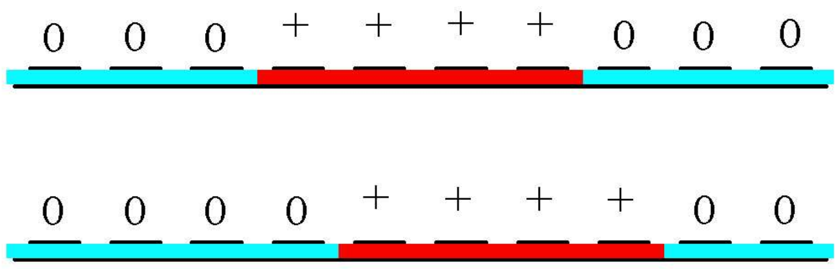


How does superluminal emission work? Look at Maxwell's equations

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J}_{\mathrm{free}} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \frac{\partial \mathbf{P}}{\partial t}$$

Propagation terms in green. Usual sources (aerials, synchrotrons) employ $\mathbf{J}_{\mathrm{free}}$ of electrons, restricted to $v < c$. Our source uses *polarization current* $\partial\mathbf{P}/\partial t$; no restriction on speed of polarization current: $v > c$.



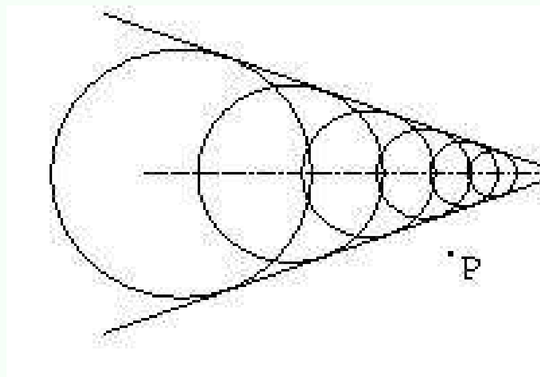
Side view (above)

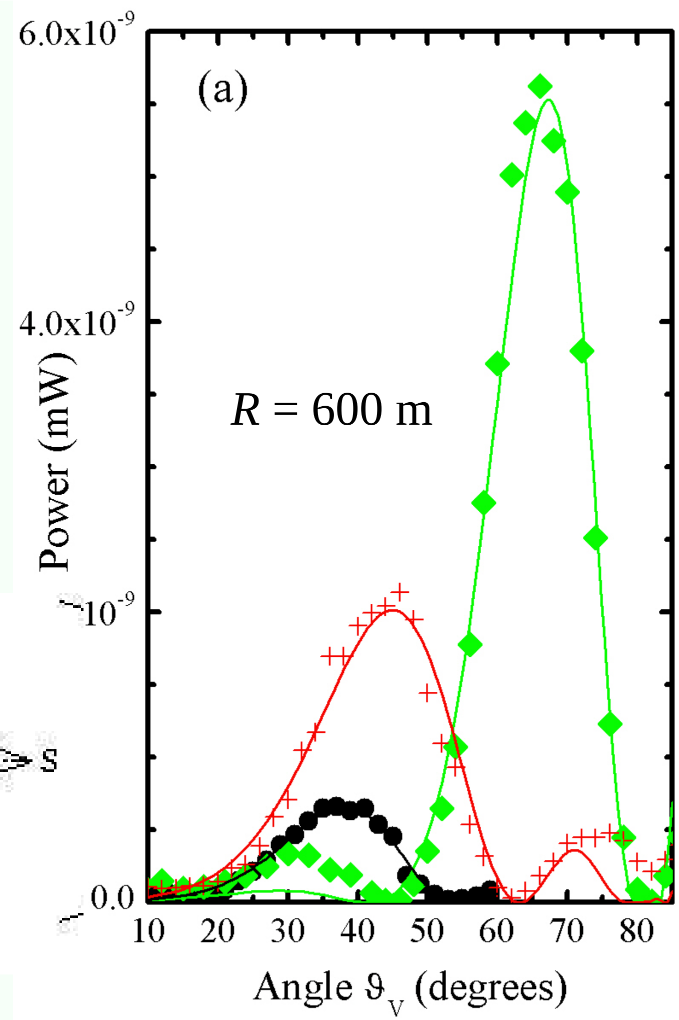
Plan view

Left: moving a region of **P** (red) along a dielectric (blue) by switching voltages on the electrodes on and off. Right: the existing practical device.

Does it work? Simplest test: can we get Cerenkov radiation into the vacuum? Yes!

Beaming tests with the experimental machine vertical.





Expect Çerenkov-like emission peaked at $\theta_V = \arcsin\{R/R_P\,[1-(mc/nv)^2]^{1/2}\}$ with $n = 2\pi f/\omega$; $m = \eta/\omega$. Data are for $\eta/2\pi$ = 552.654 MHz, $\Omega/2\pi$ = 46.042 MHz and $f = |\Omega+\eta|/2\pi$: speed v/c = 1.06 (dots), 1.25 (crosses), 2.00 (diamonds).

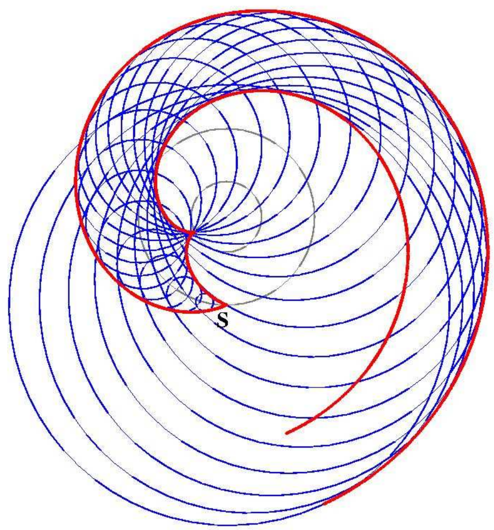
Emission moves to higher angles as v increases. *Curves are model with source speed as input.*

Note narrow "beam", even though the machine is ~ 1/50 wavelength by 1 wavelength in area!

The lack of diffraction is because this "beam" represents *temporal*, rather than spatial focusing.

A special feature of superluminal sources: multiple retarded times, or (with acceleration) *extended* retarded times contribute to the signal.

Simple example: rotating source.



- Spherical wavelets from rotating source.
- Cross-section of envelope in orbit plane.
- Orbit and light cylinder ($r = c/\omega$).

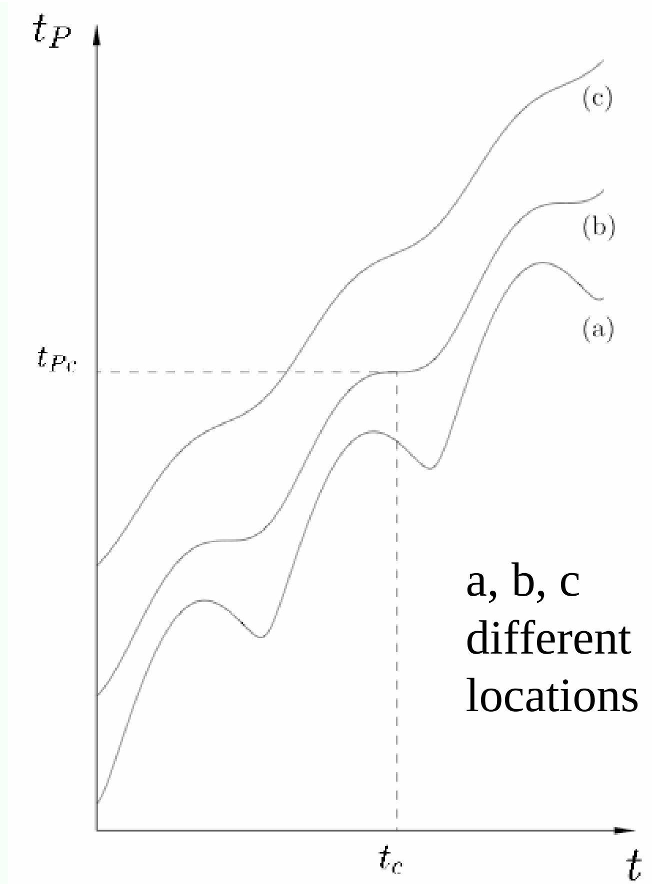
Source: $r = \text{const}, \quad z = \text{const.}, \quad \varphi = \hat{\varphi} + \omega t$

Observer: $r_{\mathrm{P}},\ z_{\mathrm{P}},\ \varphi_{\mathrm{P}}$

Separation, source to observer:

$$R(t) = [(z_P - z)^2 + r_P{}^2 + r^2 - 2 r_P r \cos(\varphi_P - \hat{\varphi} - \omega t)]^{\frac{1}{2}}$$

Obs. time $t_{\mathrm{P}} = \text{source } t + \text{dist}/c = t + R_{\mathrm{P}}/c =$
$t + [(z_P - z)^2 + r_P{}^2 + r^2 - 2 r_P r \cos(\varphi_P - \hat{\varphi} - \omega t)]^{\frac{1}{2}}/c$



There is no longer a simple relationship between retarded time and reception time.

Source time/reception time- applications.

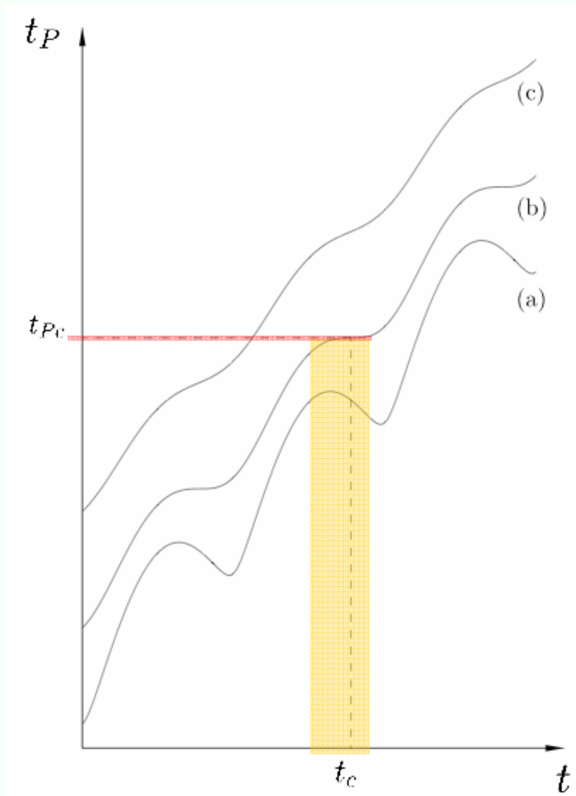
Superluminal sources: emission from multiple source times can arrive simultaneously at an observer. The very complicated relationship between source time and reception time depends sensitively on position of observer.

1) Basis of *spatial encryption*: we modulate signal so that it can only be understood at a specific point. No need for conventional encryption.

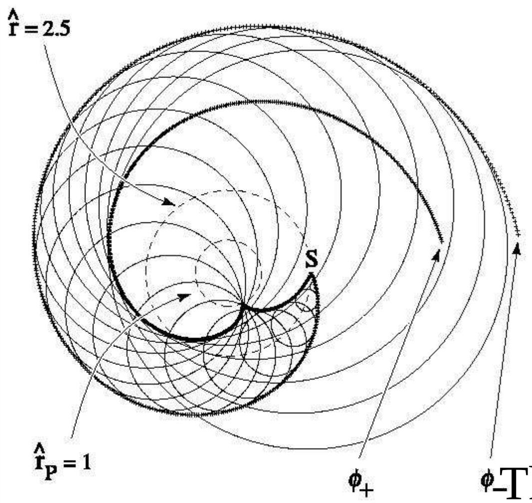
Quote from Mathematician: ‘spatial encryption is "truly incomprehensible in a mathematically rigorous way". Mathematically, this question has to do with solving an inverse problem, i.e. with reconstructing of the space-time distribution of the source out of a knowledge of the field distribution. A standard technique for tackling this sort of problem is to find the various multipole moments (dipole moment, quadrupole moment, etc) of the source distribution by determining each moment in the multipole expansion of the field. This is an effective technique when only a few moments of the source distribution matter, and when the field distribution does not vary drastically from one region to another. In the present case, however, where the Green's function for the emission process is singular, one would need to measure an essentially infinite number of multipole moments to obtain a reliable answer by this technique.’

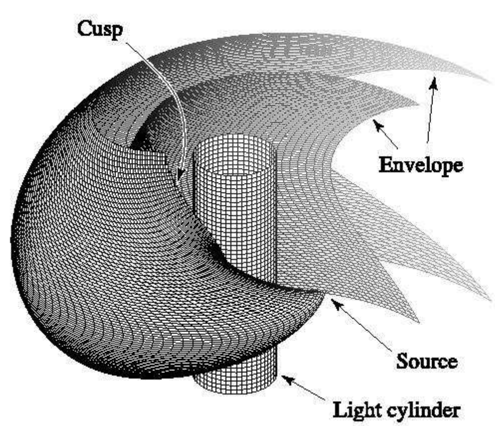
2) RADAR applications: phase fronts from a superluminal source are very scrambled so that a beam can be made countermeasure-resistant; e.g., an airplane being imaged would not be able to locate where the beam was coming from.

The cusp: a unique property of accelerated superluminal sources

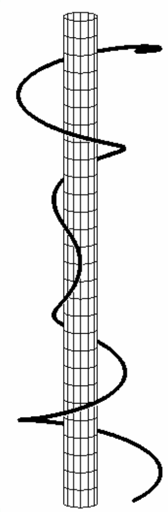


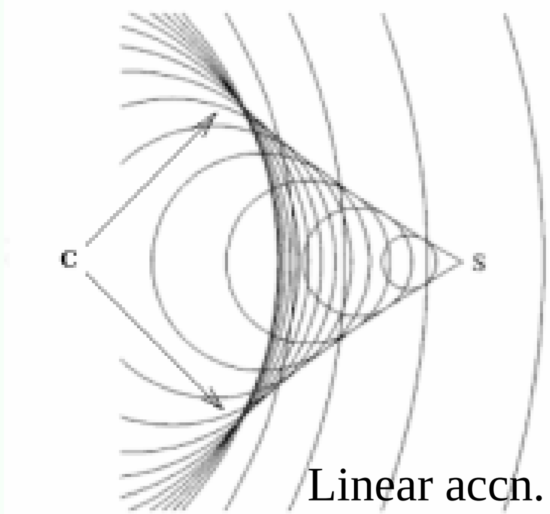
- On the cusp (b), the observer receives radiation in a very short time period that was emitted *over a considerably longer period of source time*. ⇒ There is a concentration of energy on the cusp.
- The cusp is due to source points approaching the observer at *c* and at zero acceleration. It is the fold seen in the envelope below, which spirals out from the source.
- Linearly accelerated sources show an analogous concentration of energy on each side.
- Applications in directed energy; long-range, low-power communications (power $\propto 1/R$, not $1/R^2$).





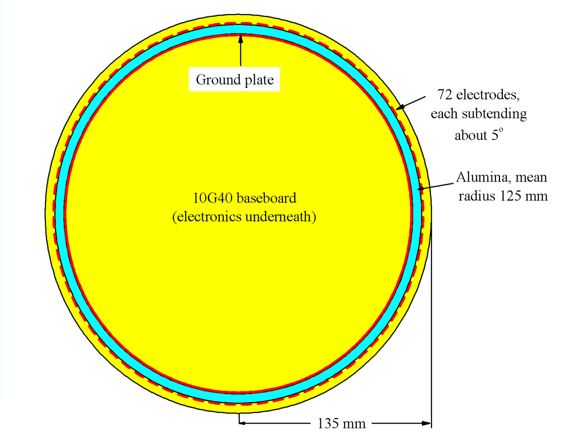
The cusp for centripetal accn.





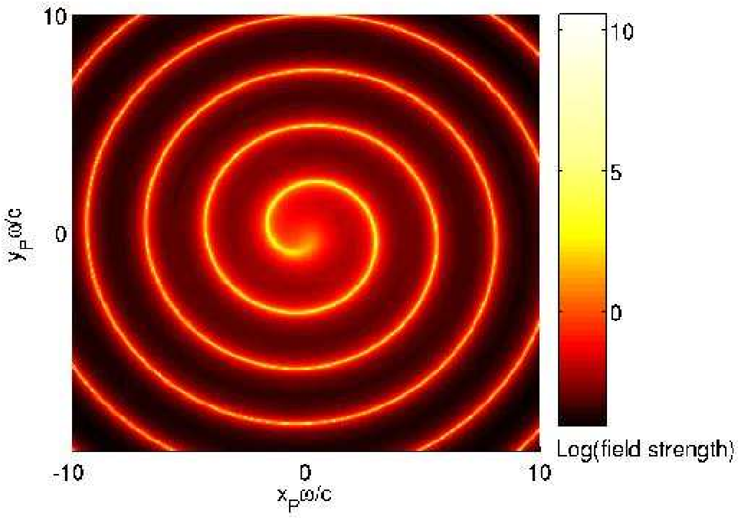
Linear accn.

•ER project a success: papers on experiments, numerical modeling, astrophysics; patent on radar; at present, our collaboration is ahead of Russian competition (based on ISKRA laser).
•But existing machine has reached limits of capability (analogue electronics; no modulation, large, unwieldy); and
•We need substantial increase in effort to maintain our leadership in this emergent field and to promote technological applications for US industry.

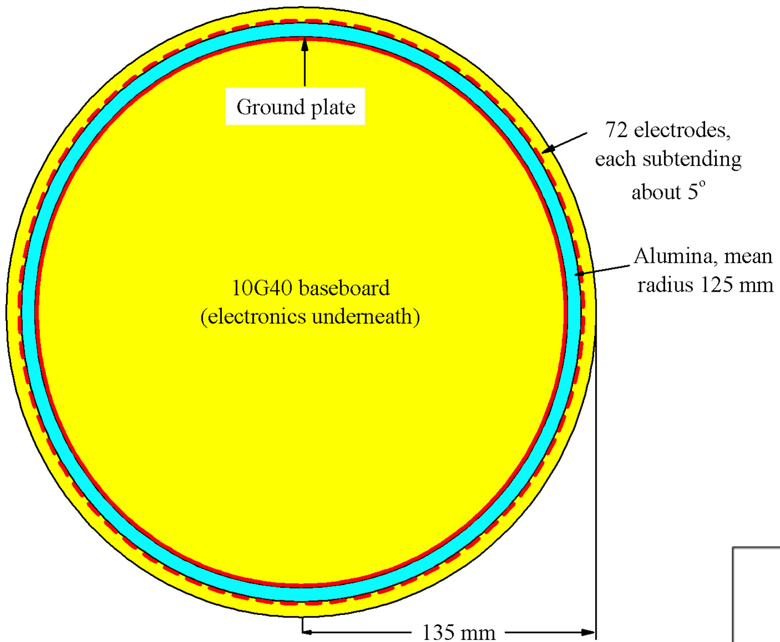


The project:

BUILD three technology demonstrators TD1, TD2, TD3;
DEMONSTRATE: use for ground-based astrophysics experiments, communications, radar and directed energy demonstrations (and commercialization)**;**
MODEL; use numerical modeling techniques to simulate experimental machines and astrophysical objects**;**
VERIFY; connect experimental, numerical and astronomical data, leading to improved understanding of all areas.



The technology demonstrators: TD1



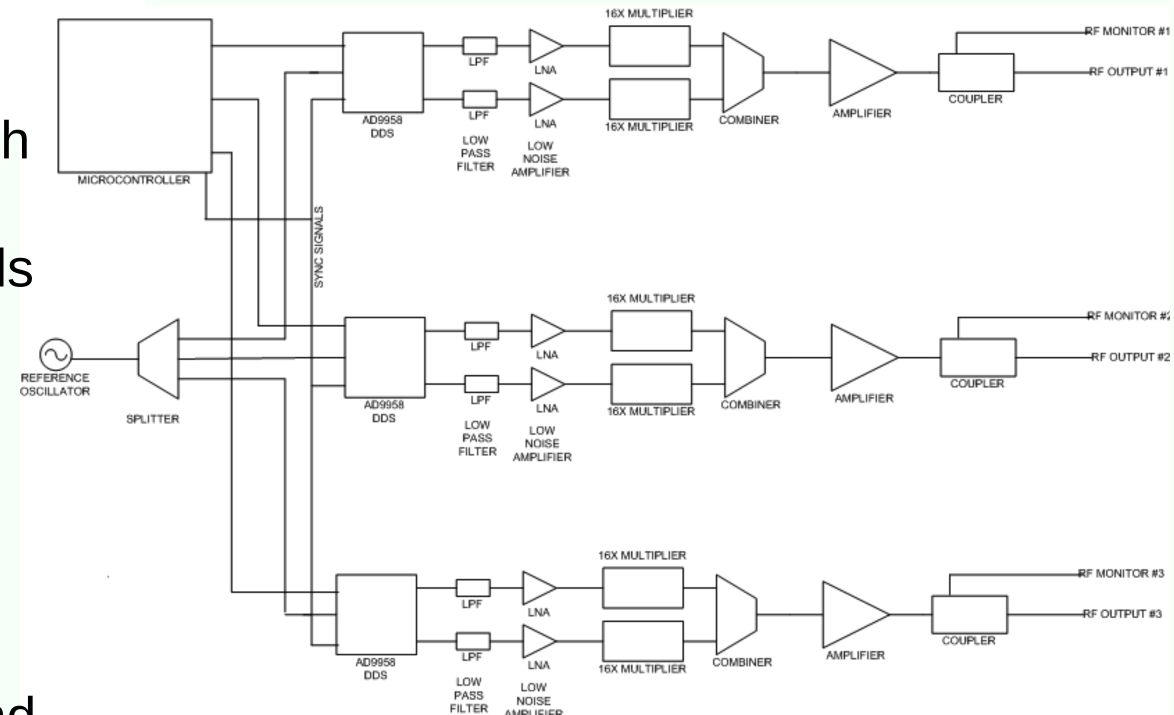
TD-1: Full-circle machine with 72 electrodes based on a 1/8 m radius (already part-designed). Build in year 1 and use as demonstrator for communication, phase-front (radar) applications, and as a ground-based astrophysical experiment (reverse engineer a pulsar).

Modular control circuit for each electrode; master PC control. Digital electronics- all channels supplied by common clock (crystal oscillator).

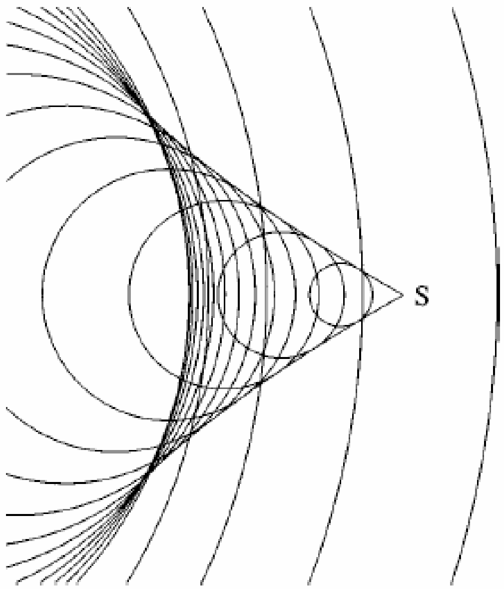
32 bit frequency tuning resolution;

14 bit phase offset resolution.

Phases of each frequency monitored by digital lock-in and iteratively adjusted.

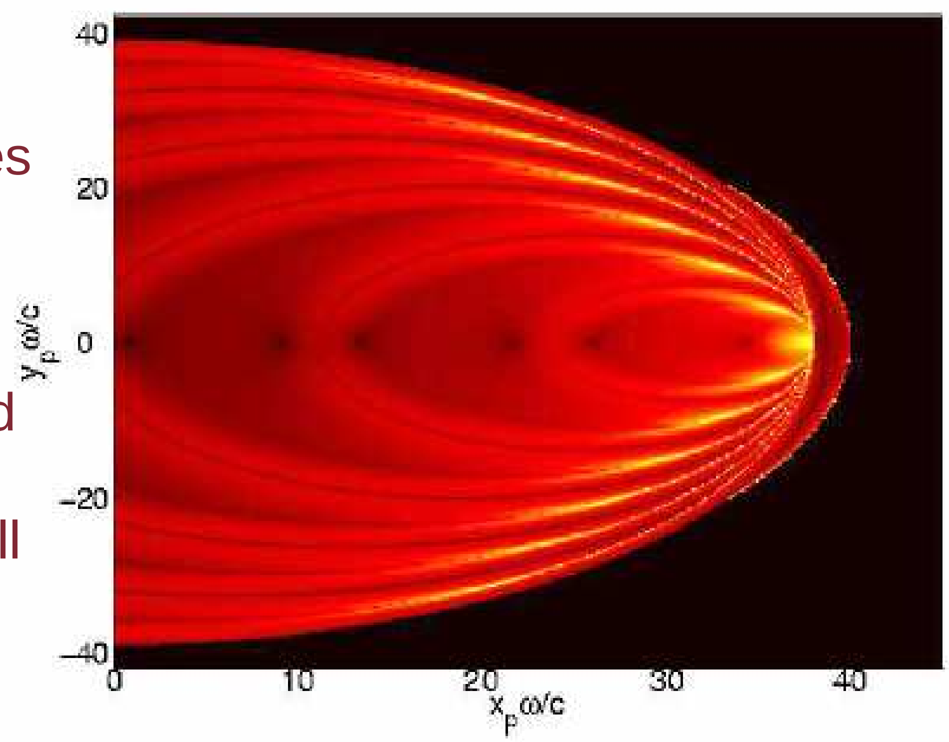


The technology demonstrators: TD2, TD3

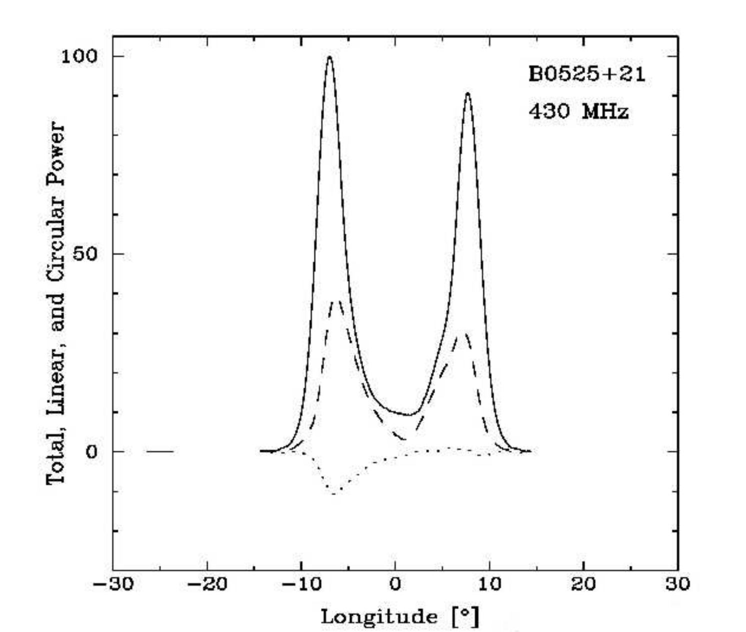


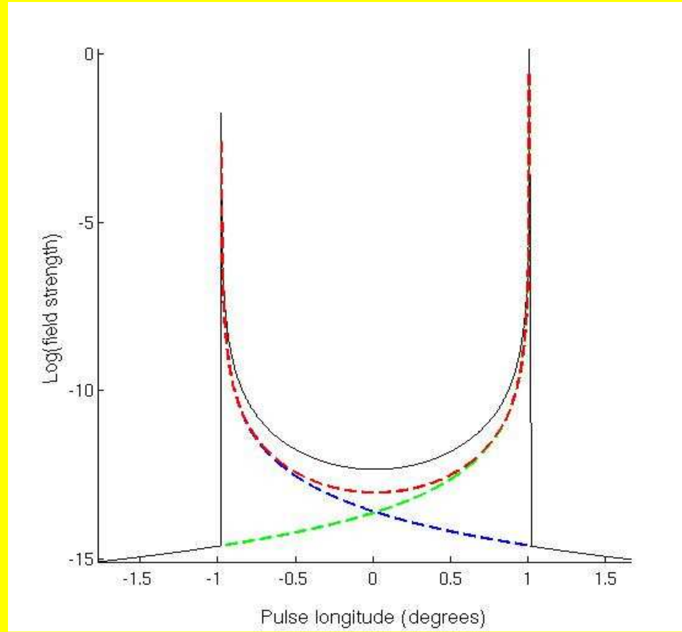
•TD-2: *linear accelerator* (directed energy applications); small machine for concept testing, superluminal shock-wave simulation (nuclear explosions, gamma-ray bursts).
•TD-3 demonstration modules for high-voltage (kV), high power directed-energy demonstrator.

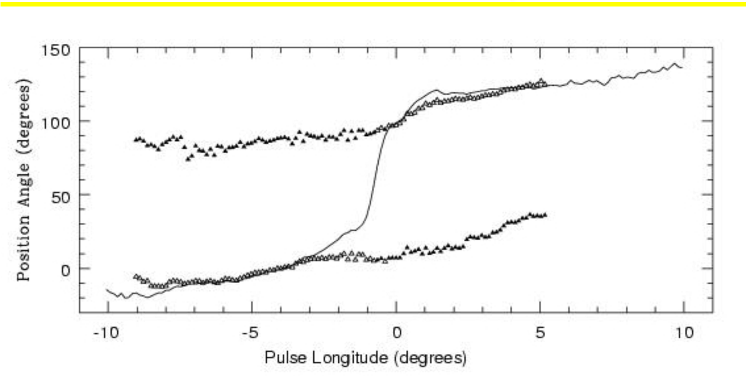
•Acceleration scheme and detailed geometry of dielectric and electrodes will be optimized in year 1, using extensive numerical modeling (example to right).
•TD2 will be built and commissioned in year 2.
•Based on results with TD2, TD3 will be built in year 3

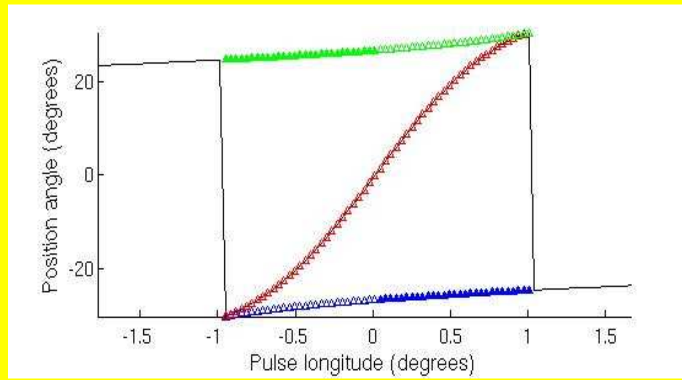


Superluminal processes in astronomy









Numerical model of rotating superluminal source (right) mimics *all* properties of pulsars (left) with a single theory: profile (top), position angle (bottom), radiation temperature, multiple images etc.. Data: Hankins and Rankin (2006), McKinnon (2003); model: Schmidt (2006).

Can we infer more about the structure of pulsars from detailed comparisons of theory, ground-based experiment and observation? How big is the emitting region? What else out there looks superluminal? Gamma-ray bursts have many of the characteristics of a superluminal source with radial acceleration, followed by a pulsar-like mechanism.

The project: why this team and why at LANL?

•John Singleton: MPA-NHMFL: PI. Co-inventor of superluminal animation; designer of experiments that verified original machine.

•Bruce Carlsten, Larry Earley: ISR-6: machine design and construction; expertise in accelerator design; high-speed, high-power electronics; test facilities on site.

•Joseph Fasel, Andrea Schmidt: AET-2: numerical modeling, encryption schemes; the only team to have successfully applied numerical methods to superluminal emission.

•Bill Junor (ISR-2), Mario Perez (ISR-1): combine astrophysics expertise with surveillance and communication activities; experience of commercialization.

•John Middleditch: CCS-3: astrophysics observations; pioneering work in pulsar observations.

•Petr Volegov: P21: signal processing; experience in superluminal emission from nuclear events.

•External: Houshang Ardavan (Cambridge University): pioneer of superluminal emission theory and its application to astronomy. Arzhang Ardavan (Oxford University): co-inventor of superluminal animation.

•Subcontractor: JP Accelerators: constructors of several successful projects of this scale and complexity for LANL.

LANL contains all of the expertise and resources needed to push this new technology forward. At present, the LANL collaboration is the world leader.